Solar Evaporator for Integrated on-Farm Drainage Management (IFDM) System at Red Rock Ranch, San Joaquin Valley, California

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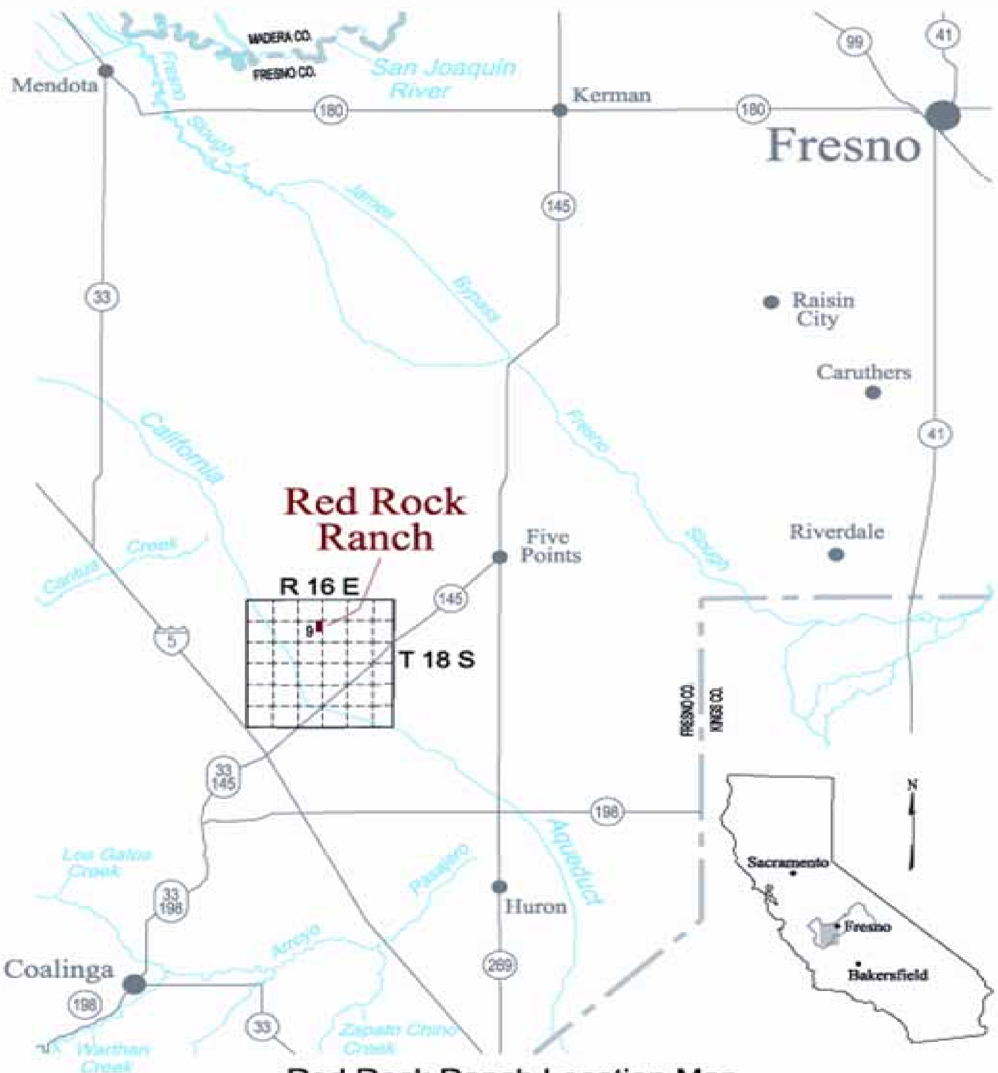
Collaborators: Mike Delamore, U.S. Bureau of Reclamation, John Diener, Jose Lopez, Red Rock Ranch.

Objectives

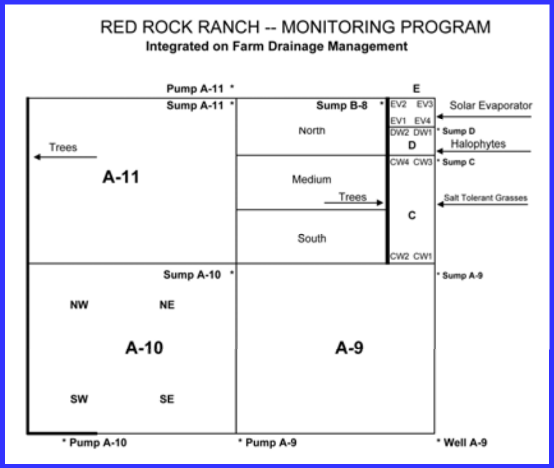
- To develop and demonstrate the use of solar evaporators as an economic, simple, and environmentally safe method to evaporate concentrated subsurface drainage water and store its salts as terminal point of an IFDM system.
- Evaluate possible recovery of drainage salts for beneficial use.

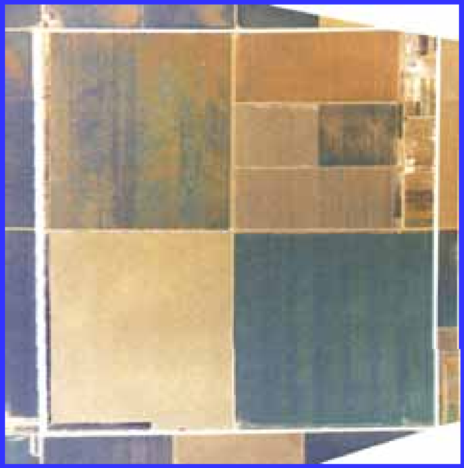


Red Rock Ranch Location Map

IFDM System at

Red Rock Ranch





- Consists of 640 acres.
- Contains four salinity zones, each with a subsurface drainage system to collect agricultural drainage water from irrigated fields.
- The IFDM system manages irrigation water on salt-sensitive high value crops (tomatoes, wheat) and reuses drainage water to irrigate salt-tolerant crops (alfalfa, cotton, tall wheat grass), salt-tolerant trees, and halophyte (saltgrass, iodine bush) plants.
- Each sequential reuse reduces the volume of drainage water and increases the salt concentration.
- Drainage water (DW) too saline for irrigation is applied to the solar evaporator (SE).
- Manage salts and drainage water on-farm.
- Collect the salts for potential commercial and/or industrial reuse.

Methodology of Solar Evaporator Research

-Evaluate surface configuration to enhance evaporation, prevent standing water and therefore access to wildlife;

-Evaluate gravel materials for solar evaporator surface for solar heat absorption and wildlife protection;

-Evaluate and select water spray devices (spray patterns, angles, and pressures);

-Estimate weather parameters for seasonal and optimal operation a solar evaporator;

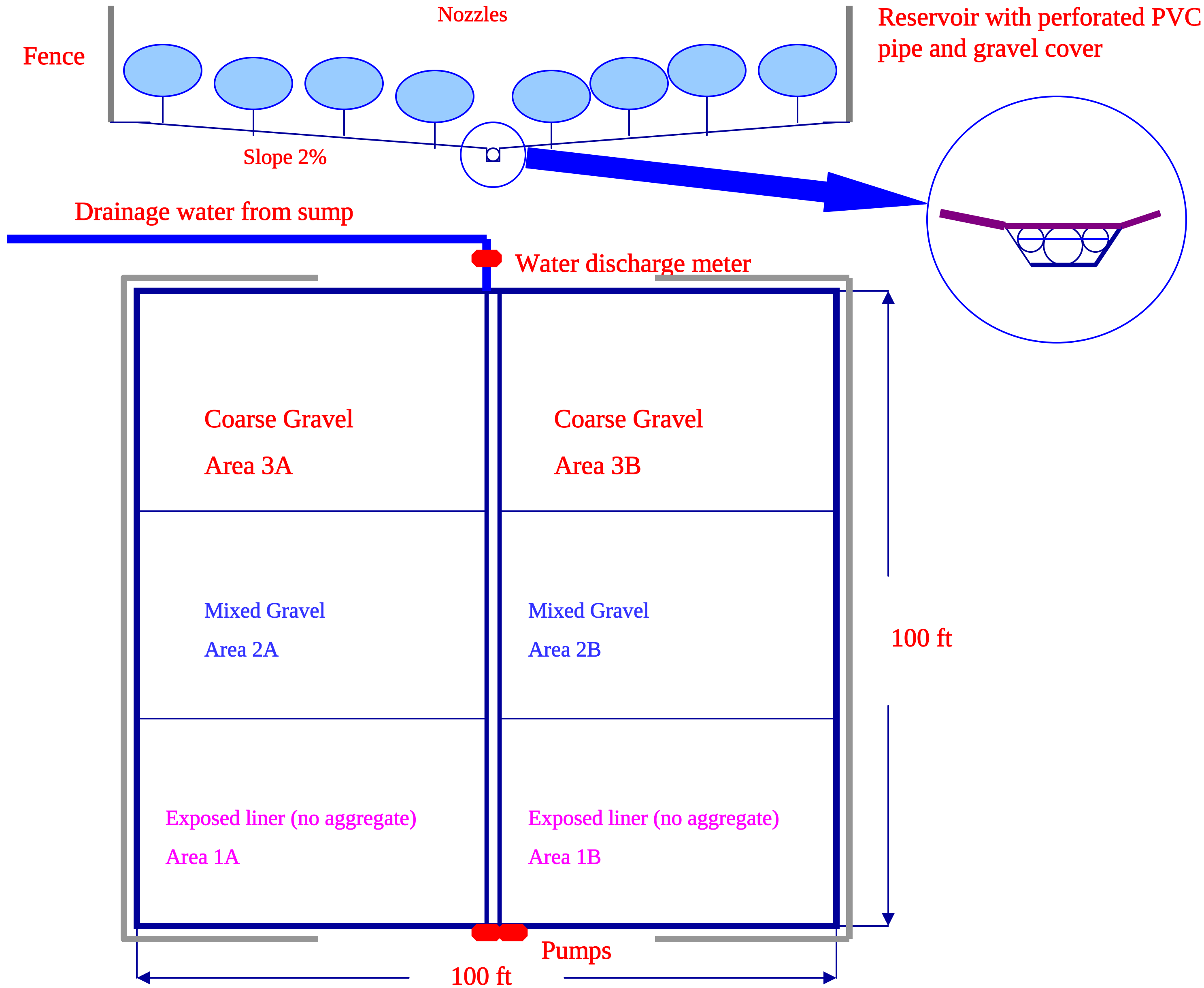
-Measure and evaluate methods to control salt drift;

-Explore separation of usable salts;

-Determine preliminary costs and O&M procedures;

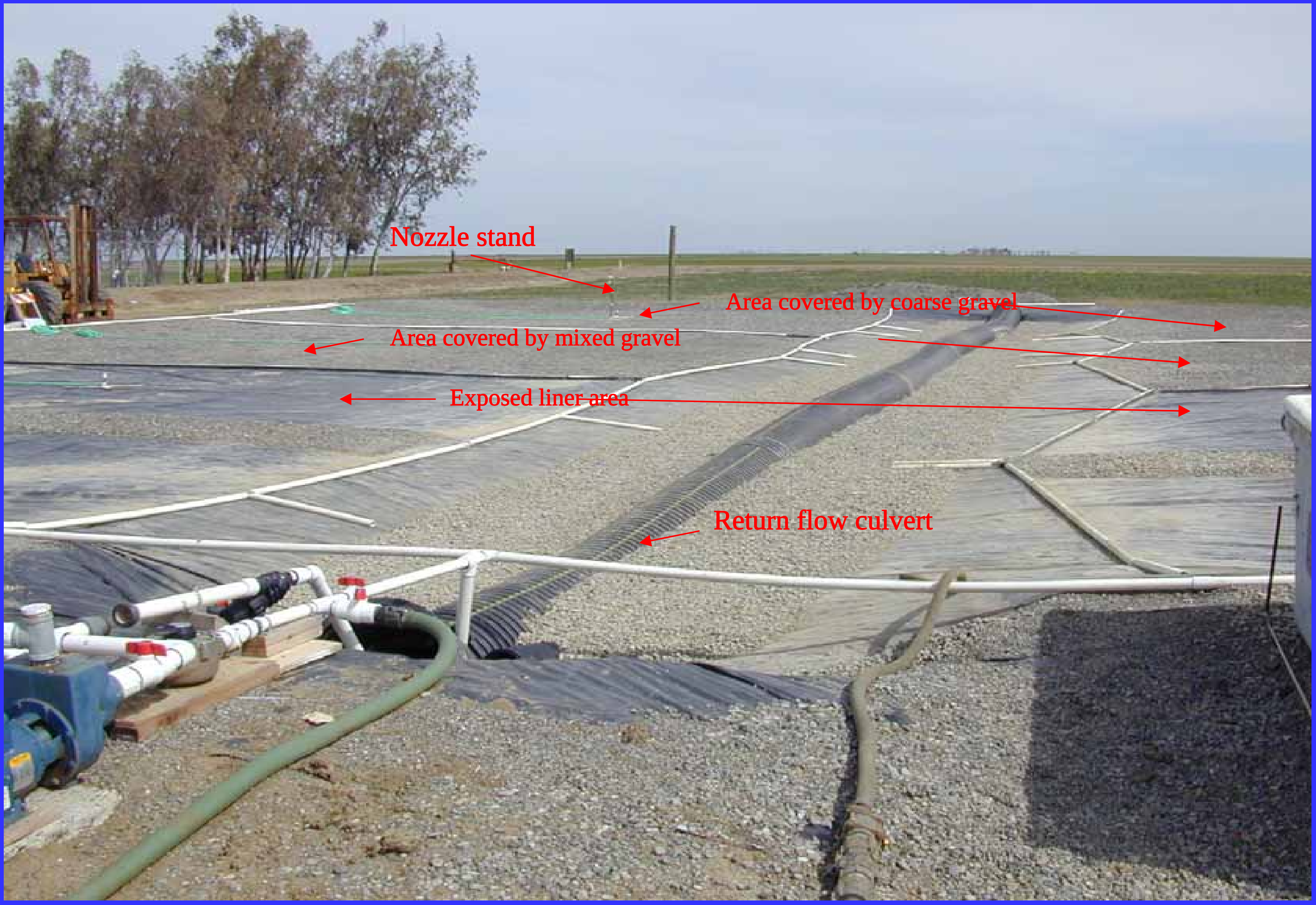
Solar Evaporator Pilot Project

Evaluation of configuration, volume, slope and cover materials



Pilot Solar Evaporator RRR

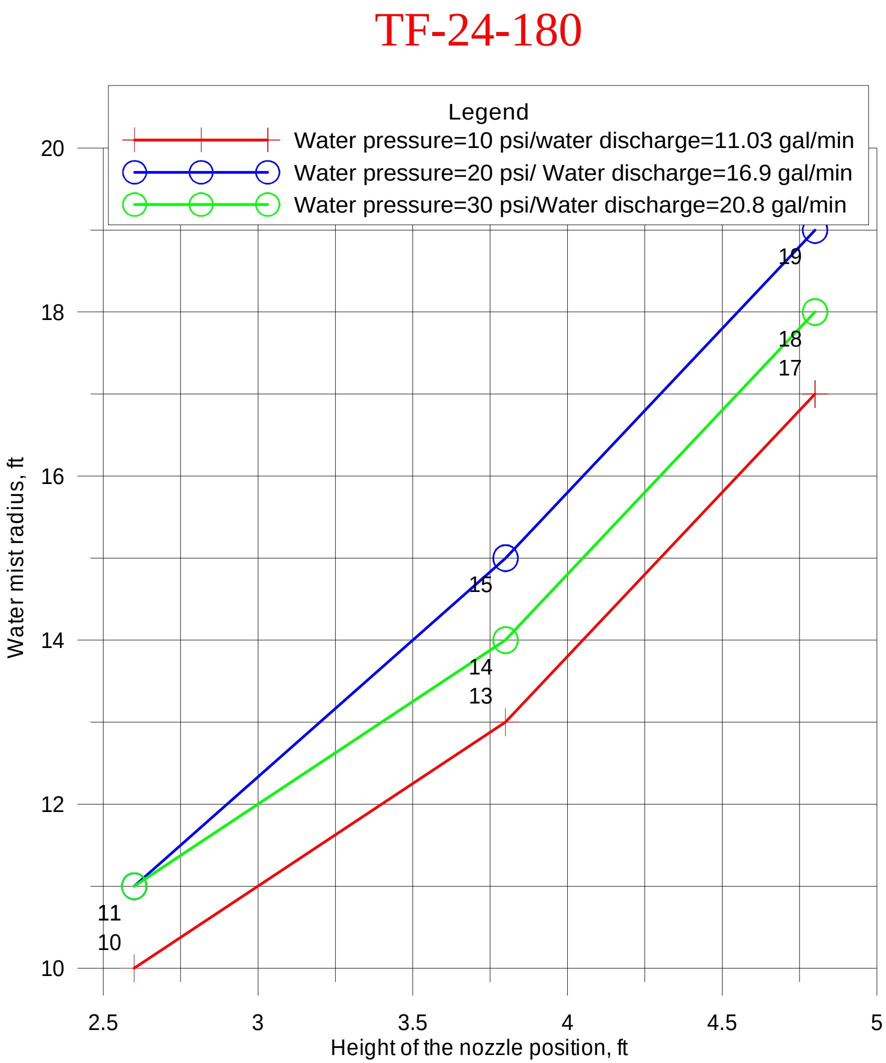
Types of Gravel Evaluated

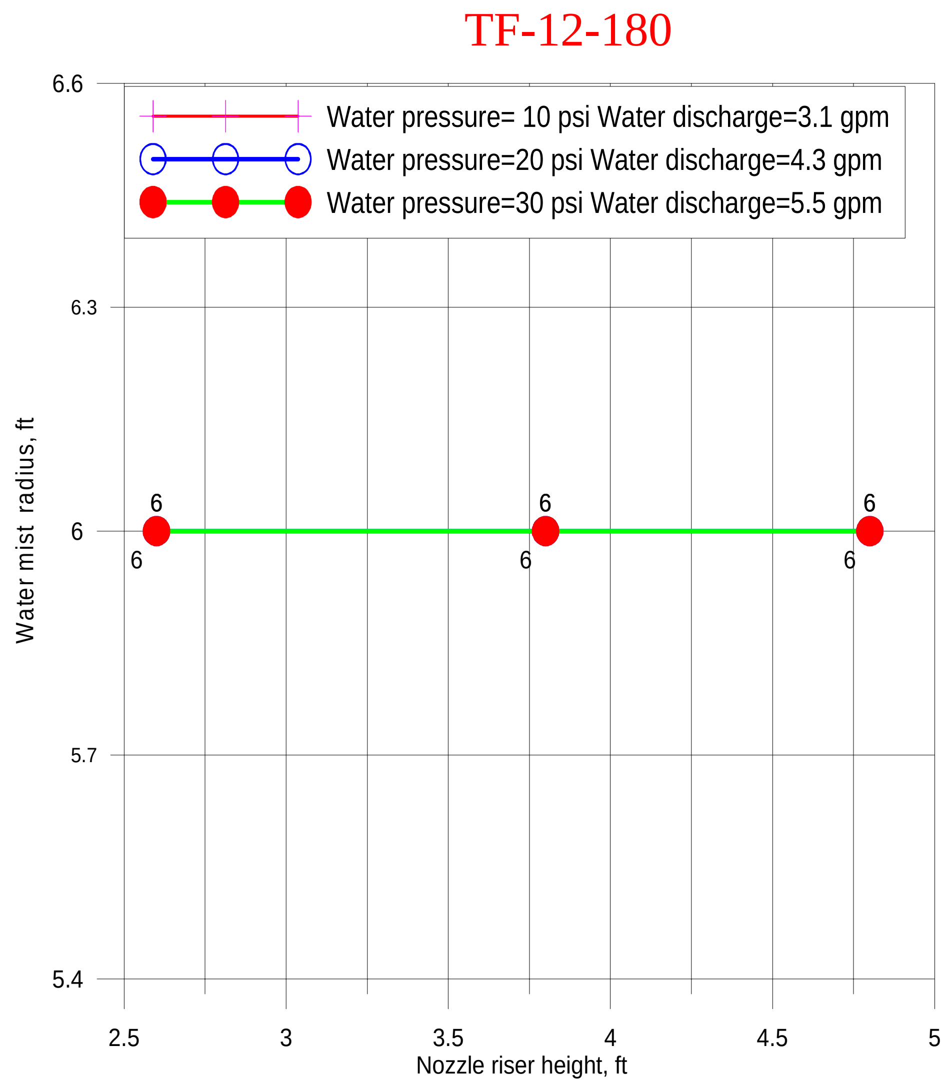


Solar Evaporator Test: Evaporative Surfaces

Spray Devices Tests at the Center for Irrigation Technology Testing Facility at California State University, Fresno

Test Nozzles





Nozzles BETE TF-24-180 and TF-12-180

(water mist radius are measured for different nozzle risers, water flow discharges, and pressures)

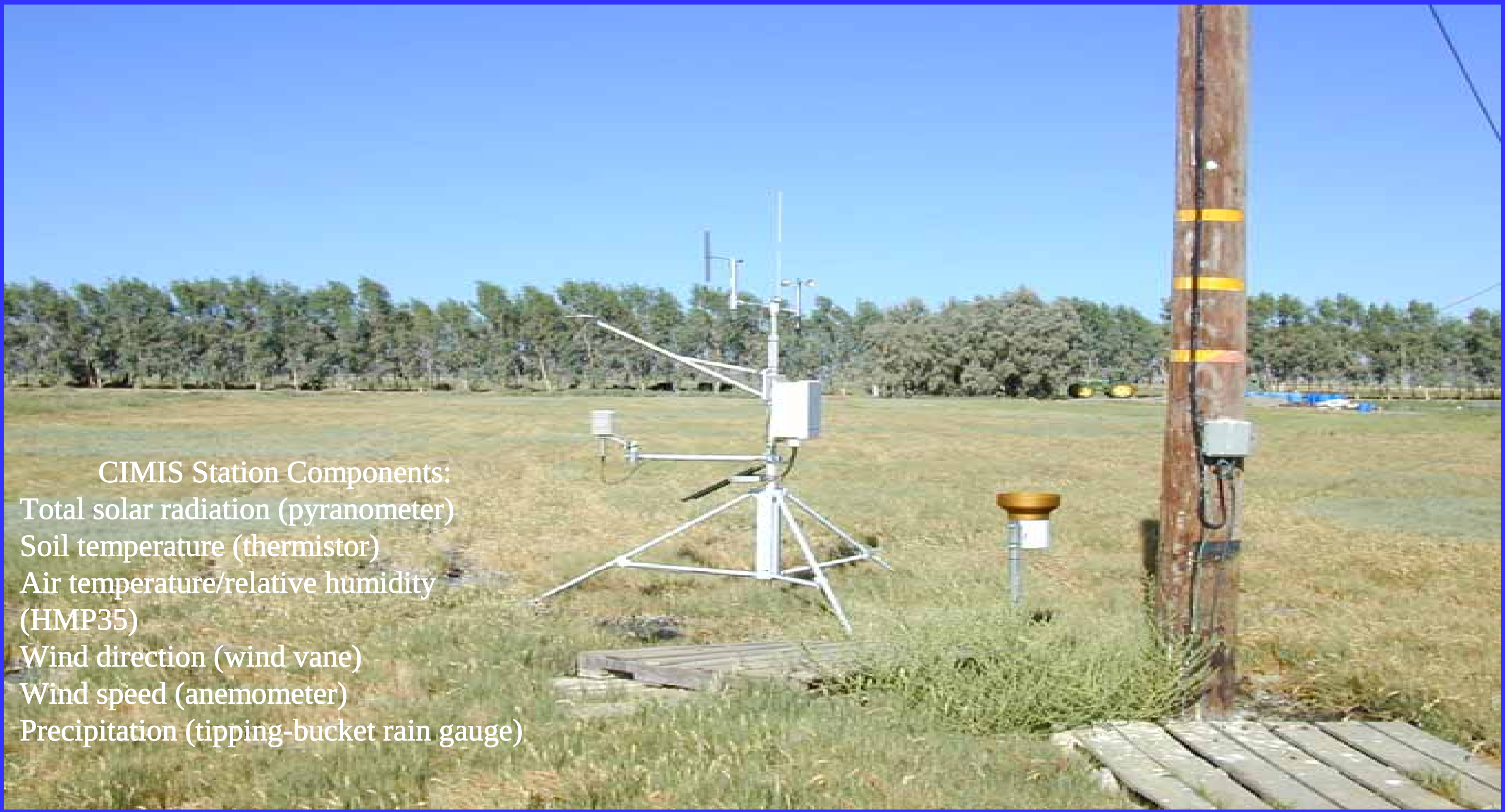
Spray Nozzle Tests

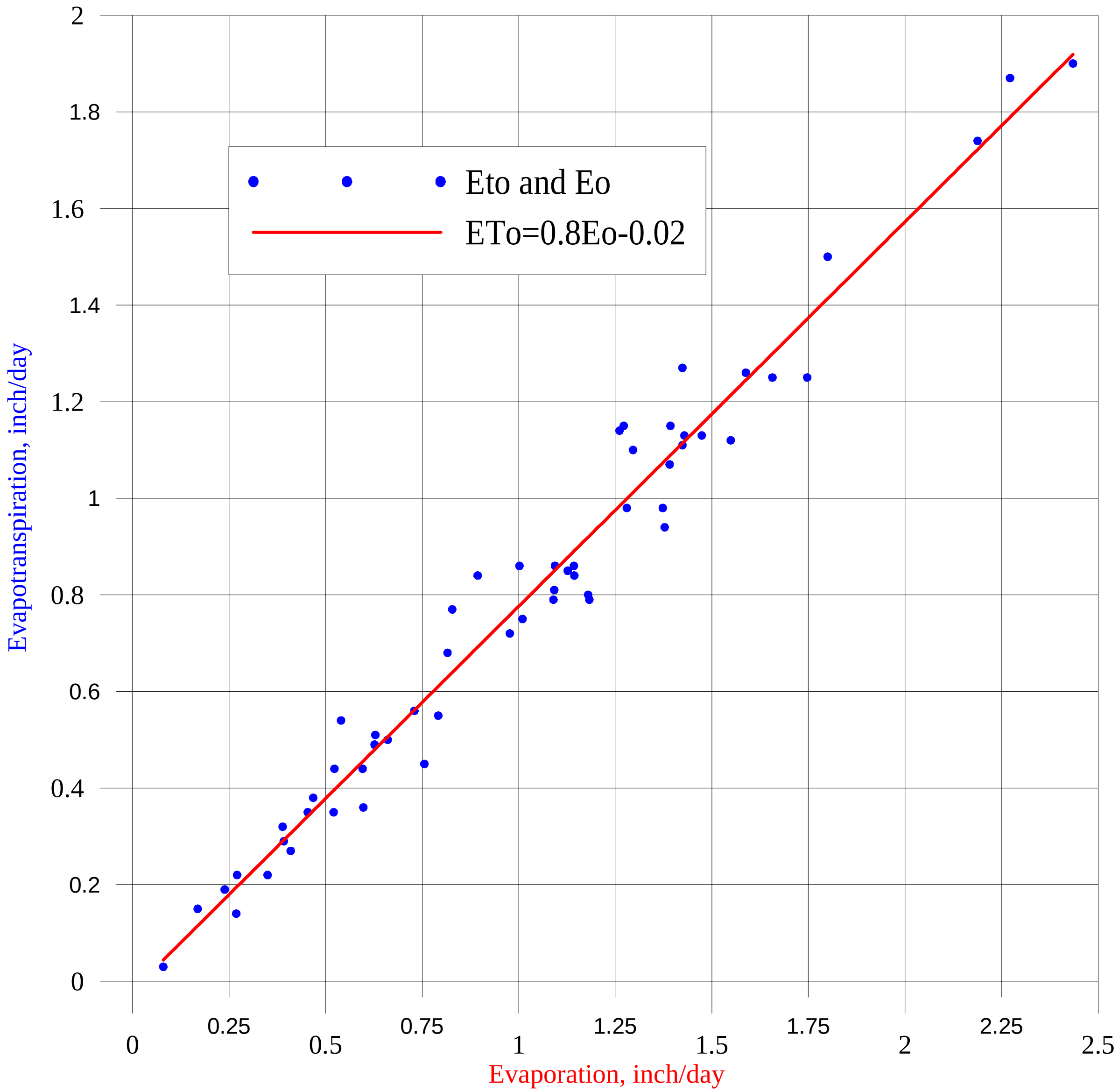
Vertically oriented nozzle position with different riser heights were tested in 2003 (riser=1.5 ft) note windbreak fence

Horizontally oriented nozzle position with different riser heights were tested in 2004 (riser=1.5 ft)

Nozzle positions with different angles and with varying riser heights were tested in 2003 (riser=1.0 ft)

Measuring Weather Parameters





Linear Equation ETo= 0.8Eo- 0.02 or Eo=1.25ETo-0.025

Number of data points used = 56

Average Eo= 1.01205

Average ETo= 0.785893

Residual sum of squares = 0.308747

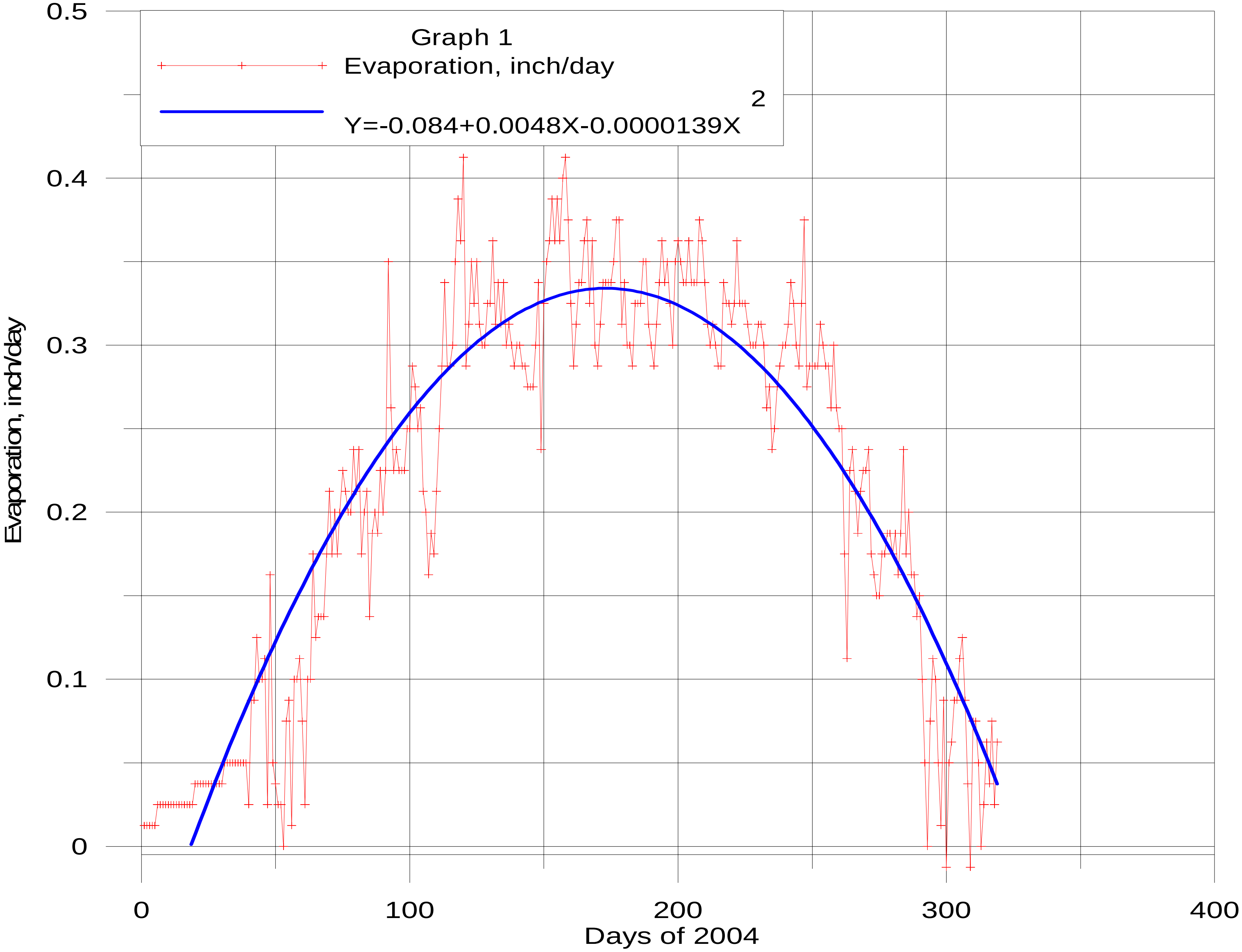
Regression sum of squares = 10.1932

Coef of determination, R-squared = 0.970601

Residual mean square, sigma-hat-sq'd = 0.00571754

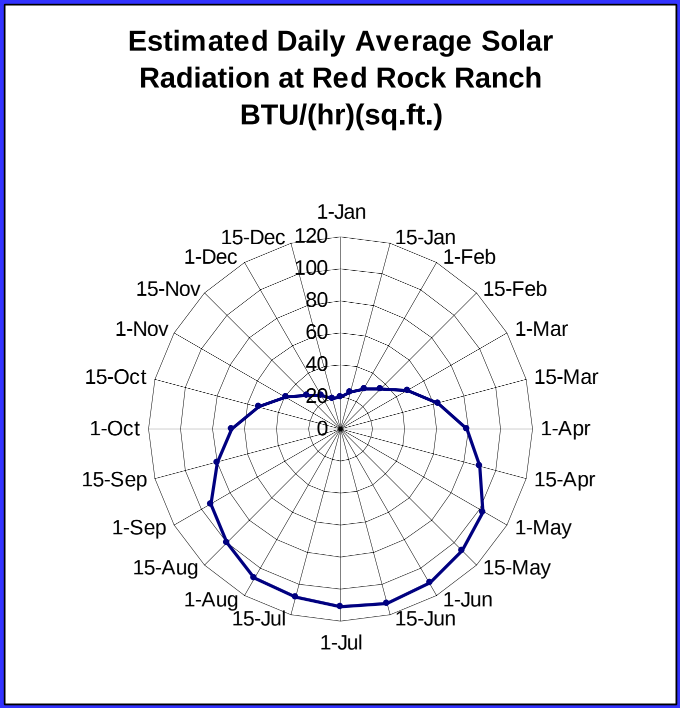
$$\boxed{Eo=1.25ETo-0.025}$$

Evaporation by Pan (Five Point Station) and Evapotranspiration by CIMIS at RRR



Daily Evaporation by CIMIS at RRR, 2004

- Measuring Enhanced Solar Evaporation



Energy Demand for Evaporation

- Heat of Vaporization:

  1,045.55 BTU/lb H_2O
- $Q_{net} = Q_{solar} + Q_{air} + Q_{gr}$
- Solar Radiation
- Convective Heat Transfer from Air
- Convective Heat Transfer from Gravel

Solar Evaporation
Example – mid June

- SE area is 100 x 100 ft
- Solar heat input = 27.12 million BTU/day
- Convective heat input from gravel = 6.7 million BTU/day
- Convective heat input from air = 9.26 million BTU/day
- Total heat input = 43.08 million BTU/day
- Evaporate 41,200 lbs/day of water

  = 4,935 gallons/day = 3.43 gallons/minute

  = 14.9 gallons/minute acre

Pilot Experiment Results

Nozzle riser= 1.0 ft

Nozzle riser= 1.5 ft

RRR - SOLAR EVAPORATOR
OPERATIONAL DATA

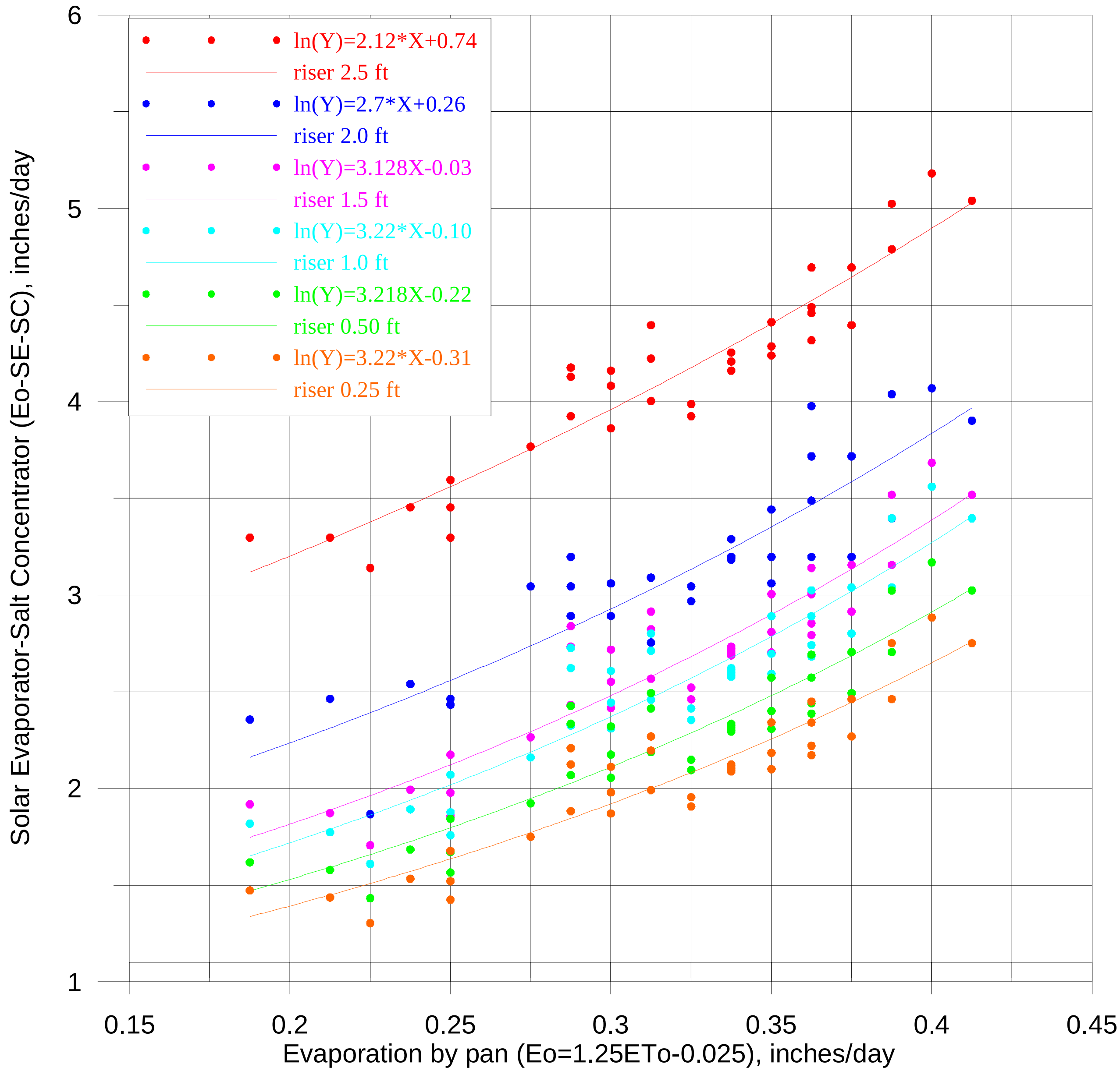
JUNE, 2003

DATE/parameters	DATE 6/9/2003	DATE 6/10/2003	DATE 6/11/2003	DATE 6/12/2003	DATE 6/13/2003	DATE 6/14/2003
Time,start	10.50 am	9.20 am	7.55 am	**Tomato**	10.20 am	6.43 am
Time,finish	11.10 am	9.40 am	8.20 pm	**Tank**	10.30 am	7.08 am
Time duration,min	**20 min**	**20 min**	**25 min**		**10 min**	**25 min**
Input reading,start	67400	69600	72000		**74800**	**75900**
Input reading,finish	69500	72100	74800		75900	78700
Input gallons	**2100**	**2500**	**2800**	**3160**	**1100**	**2800**
EC	13.83	14.5	17.3	61.5	17.63	16.21
Tem, C	22.1	19.1	21.8	20.7	22.8	20.2
PPT,garm/L	8.5	8.4	10.1	41.1	10.4	9.6

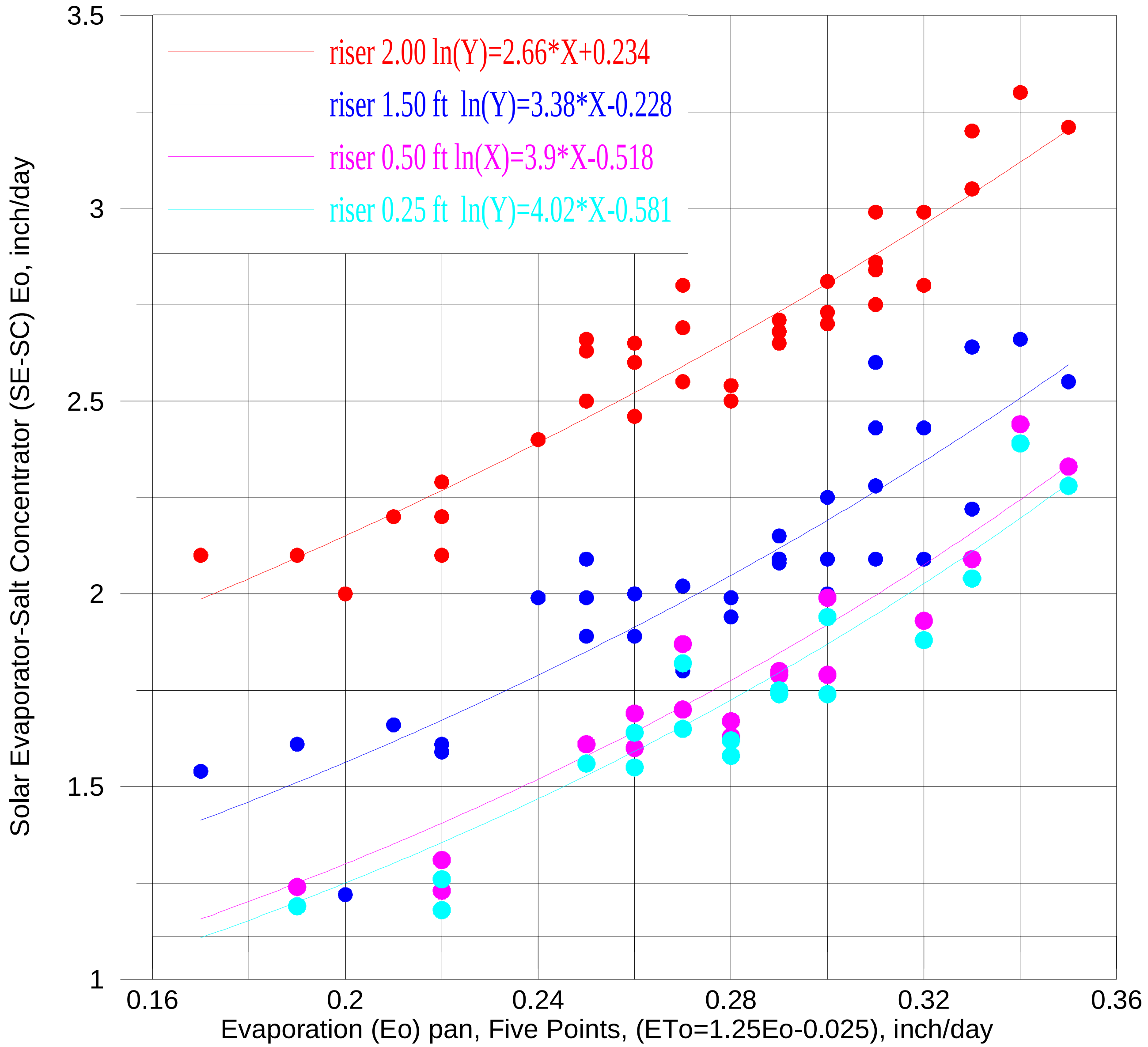
SE running						
Time,start	11.15 am	9.40 am	8.30 am	8.30 am	10.40 am	7.20 am
Time,finish	4.15 pm	5.40 pm	5.30 pm	7.30 pm	1.40 pm	4.20 pm
Time duration,min	**5 hour**	**8 hour**	**9 hour**	**11 hour**	**3 hour**	**9 hour**
Output reading, start	650100	672400	701460	736800	781100	790100
Output reading,finish	672000	701000	736300	780500	789700	822600
Volume of running,gallons	**21900**	**28600**	**34840**	**43700**	**8600**	**32500**
EC	49.51	46.54	39.15	92.8	69.3	60.5
Tem, C	19.7	16.7	25.2	19.2	24.6	20.6
PPT, gram/L	32.4	30.3	25.3	66.7	47.4	40.8
Pressure,psi	58	58	58	58	58	
Evaporation rate,gallons/day		**2100**	**2300**	**2560**	**700**	

TOMATO TANK, Time	10.40 am	9.06 am	7.20 am	**6.30 am**	**9.46 am**	**6.50 am**
Moved volume,gallons	**400**	**400**	**460**	**500**	**600**	**300**
EC	47.38	48.84	46.77	41.05	92.8	60.5
Tem,C	23.7	19.8	16.6	20.1	19.2	20.5
PPT, gram/L	30.8	31.8	30.5	26.3	66.7	40.7

TOMATO TANK, Time		**NORTH,**	**SOUT**	**WEST**			
DATE 6/9/03	**EC**	68.4	67.9	66.7			
	TEM	23.4	23.5	23.4			
	PPT	46.7	46.7	45.6			



Relationship between actual pan evaporation (Eo pan) and enhanced evaporation at the pilot solar evaporator RRR, March-October 2003.

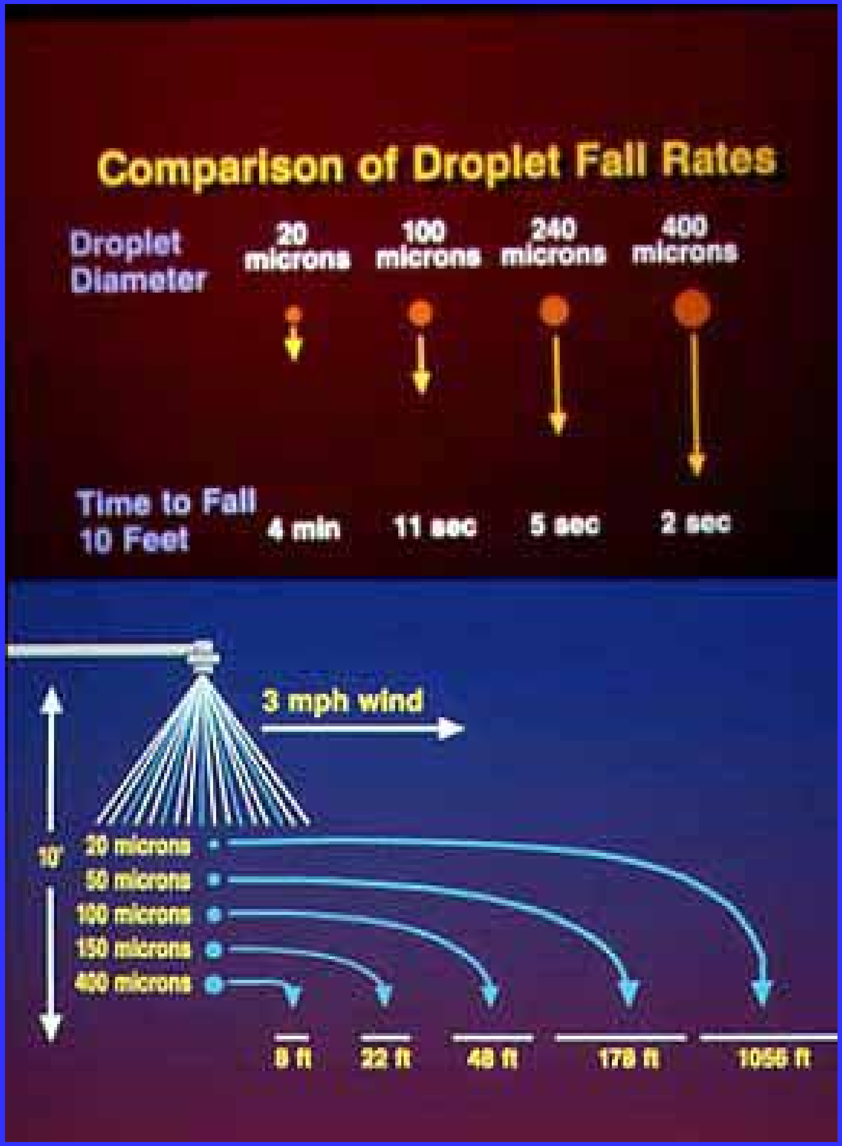


Relationship between actual evaporation (Eo pan) and enhanced evaporation

at the pilot solar evaporation RRR, March-October 2004.

Salt Drift Evaluation:
DWR
CSU-Fresno

Salt Drift Barrier Selected



Smaller droplets drift longer distances

Evaporator Salt Drift

DWR Evaluation

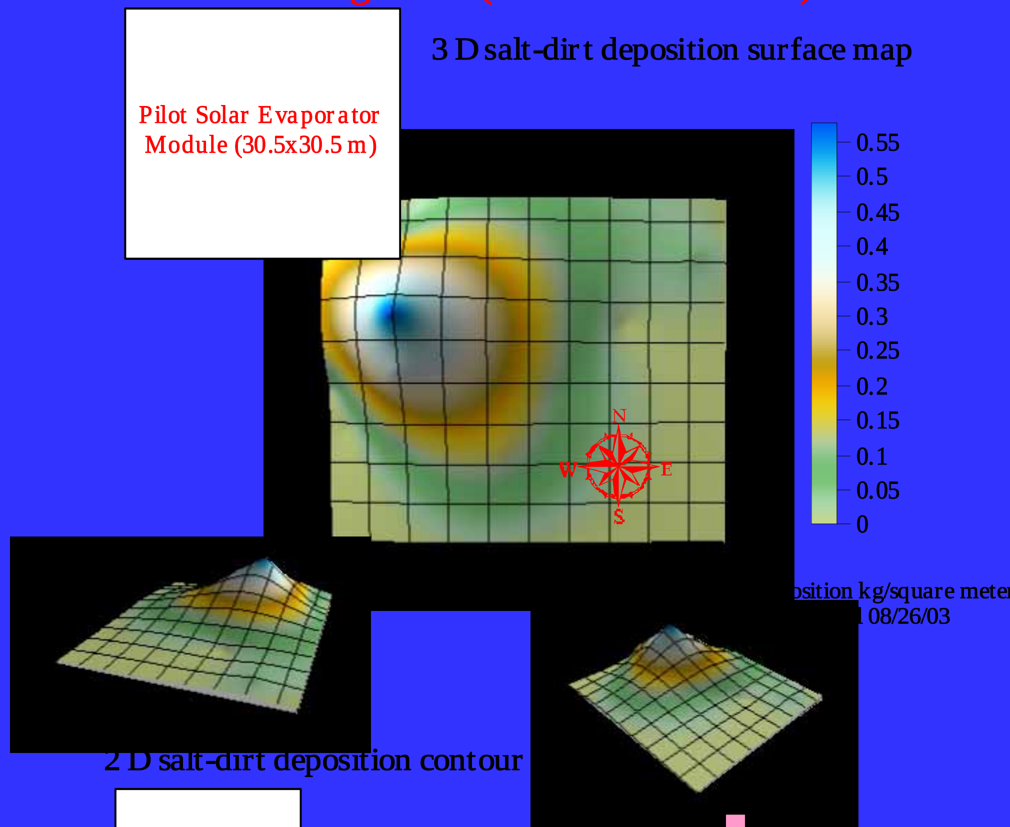
Glass plates were use to measure salt drifting outside the SE

Evaluation by DWR

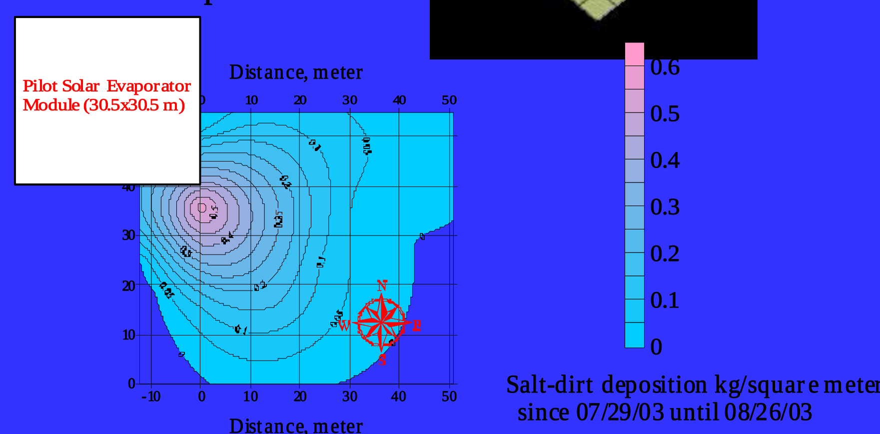
DWR Evaluation Results

Salt-dirt deposition 13.0 kg/day or
0.54 kg/hour (07/29/03-08/26/03)

3 D salt-dirt deposition surface map



2 D salt-dirt deposition contour

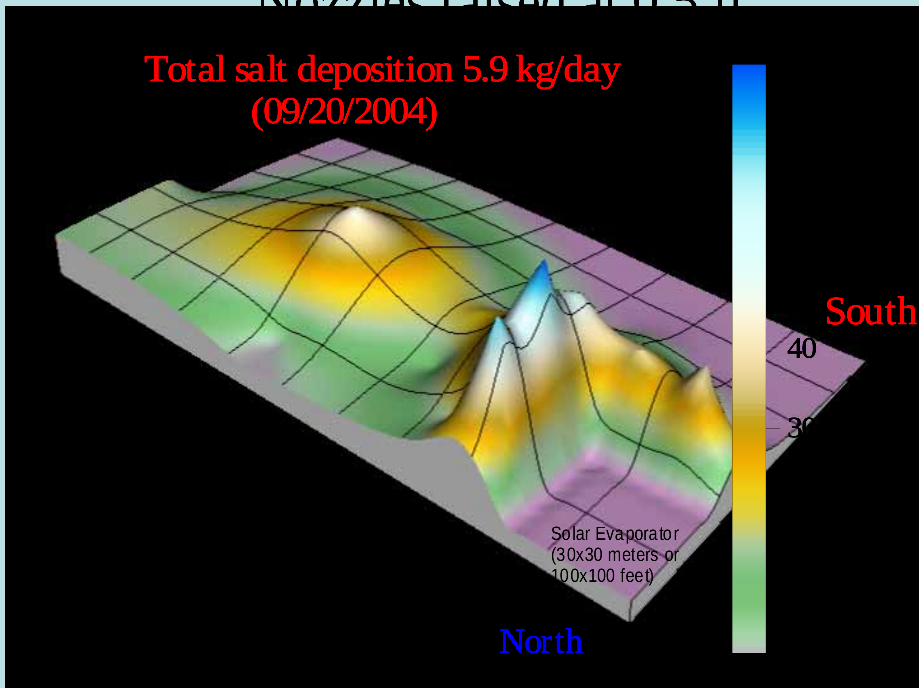


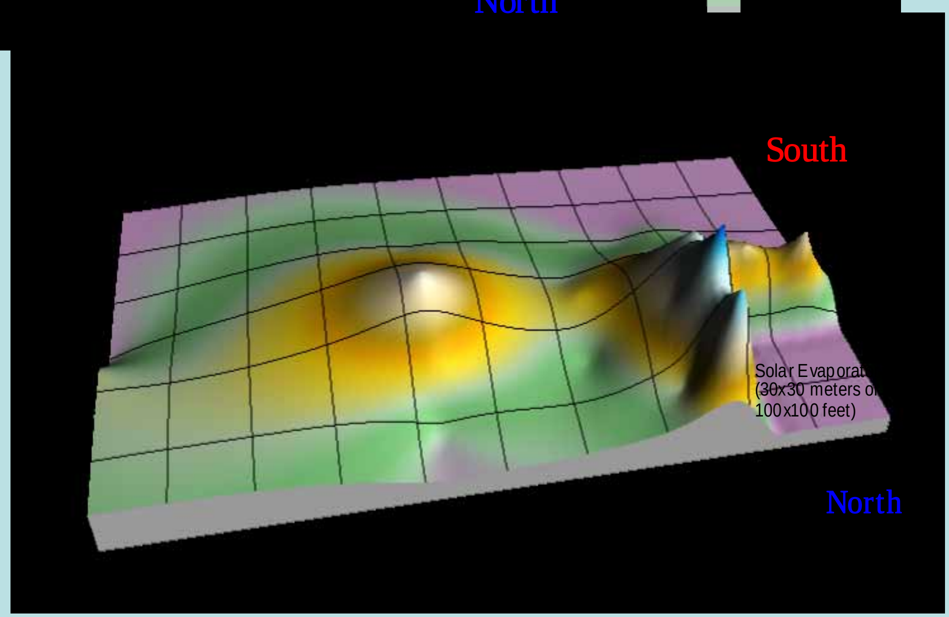
Salt Drift Evaluation

CSU-Fresno Evaluation

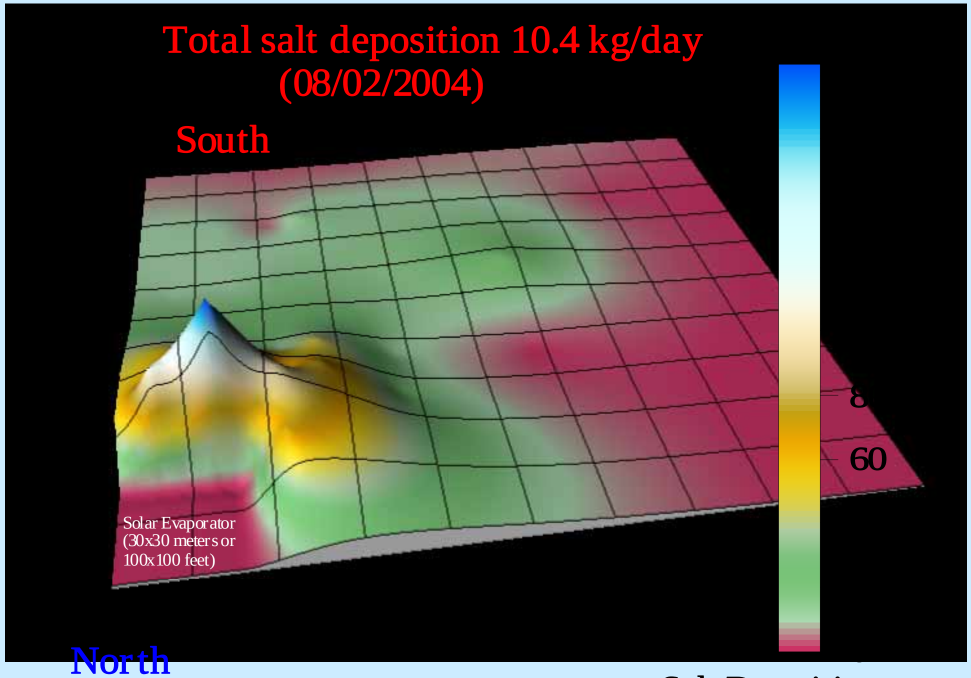
Evaluation by Professor Charles Krauter

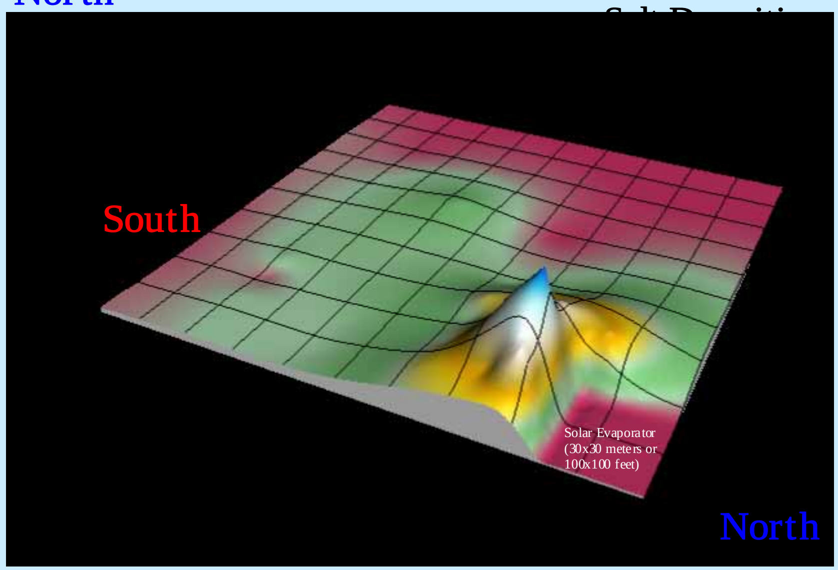
Nozzles raised at 0.5 ft



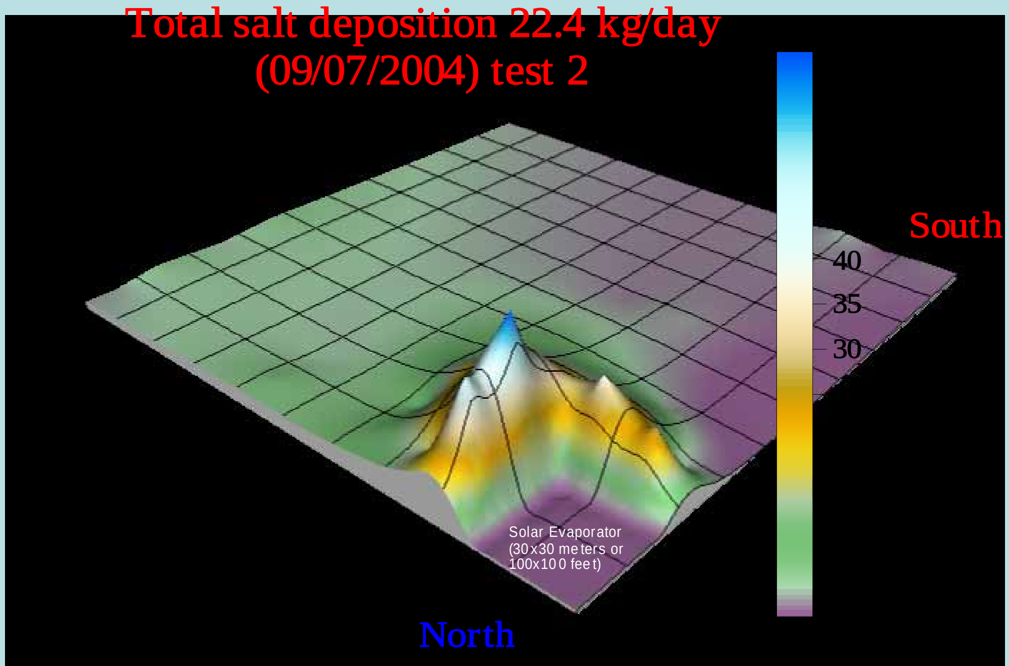


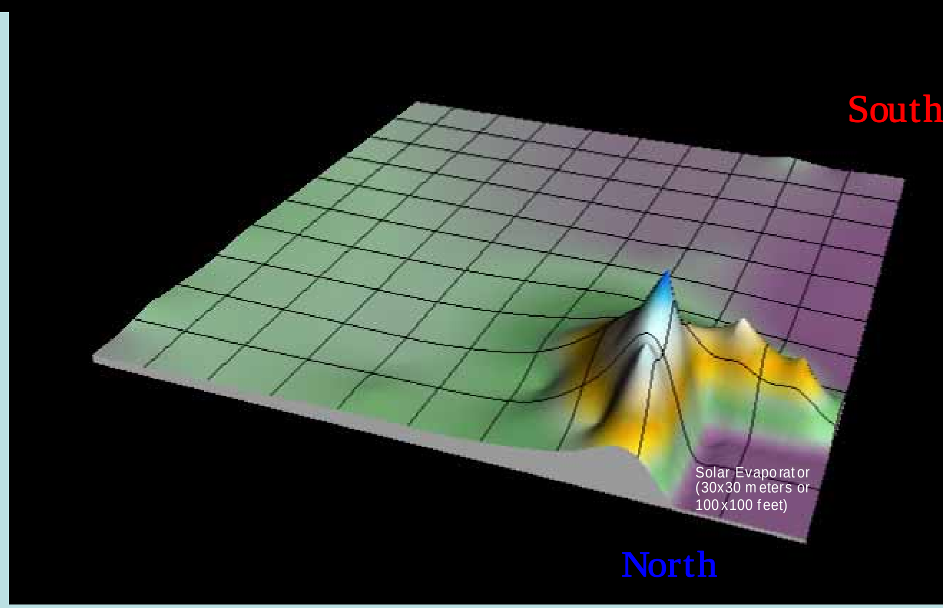
Nozzles raised at 1.5 ft

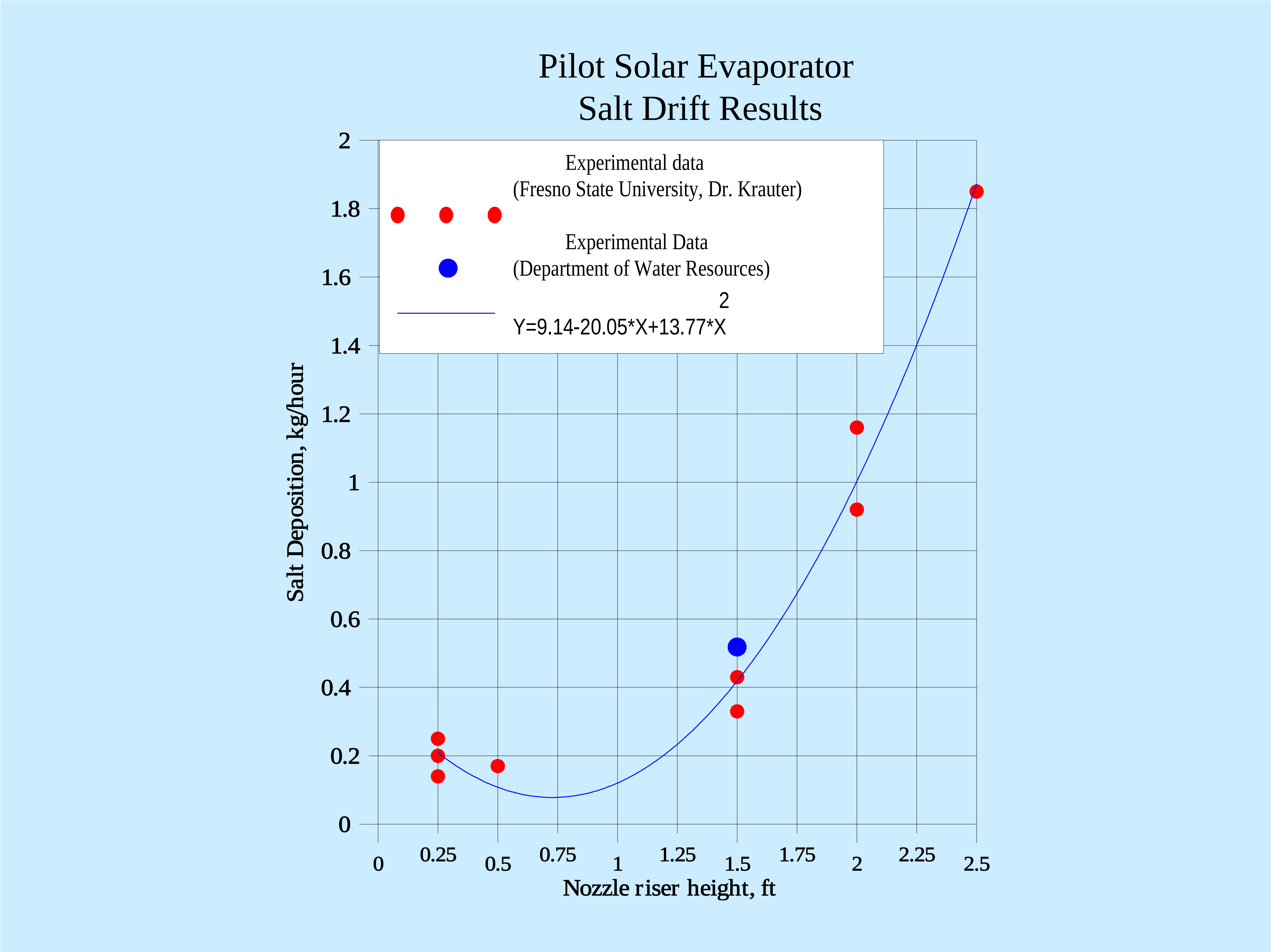




Nozzles raised at 2.0 ft







Pilot Solar Evaporator
Salt Drift Results
Experimental data
(Fresno State University, Dr. Krauter)
Experimental Data
(Department of Water Resources)
Y=9.14-20.05*X+13.77*X 2
Salt Deposition, kg/hour
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
2.25
2.5
Nozzle riser height, ft

Salt Drift Evaluation Conclusions

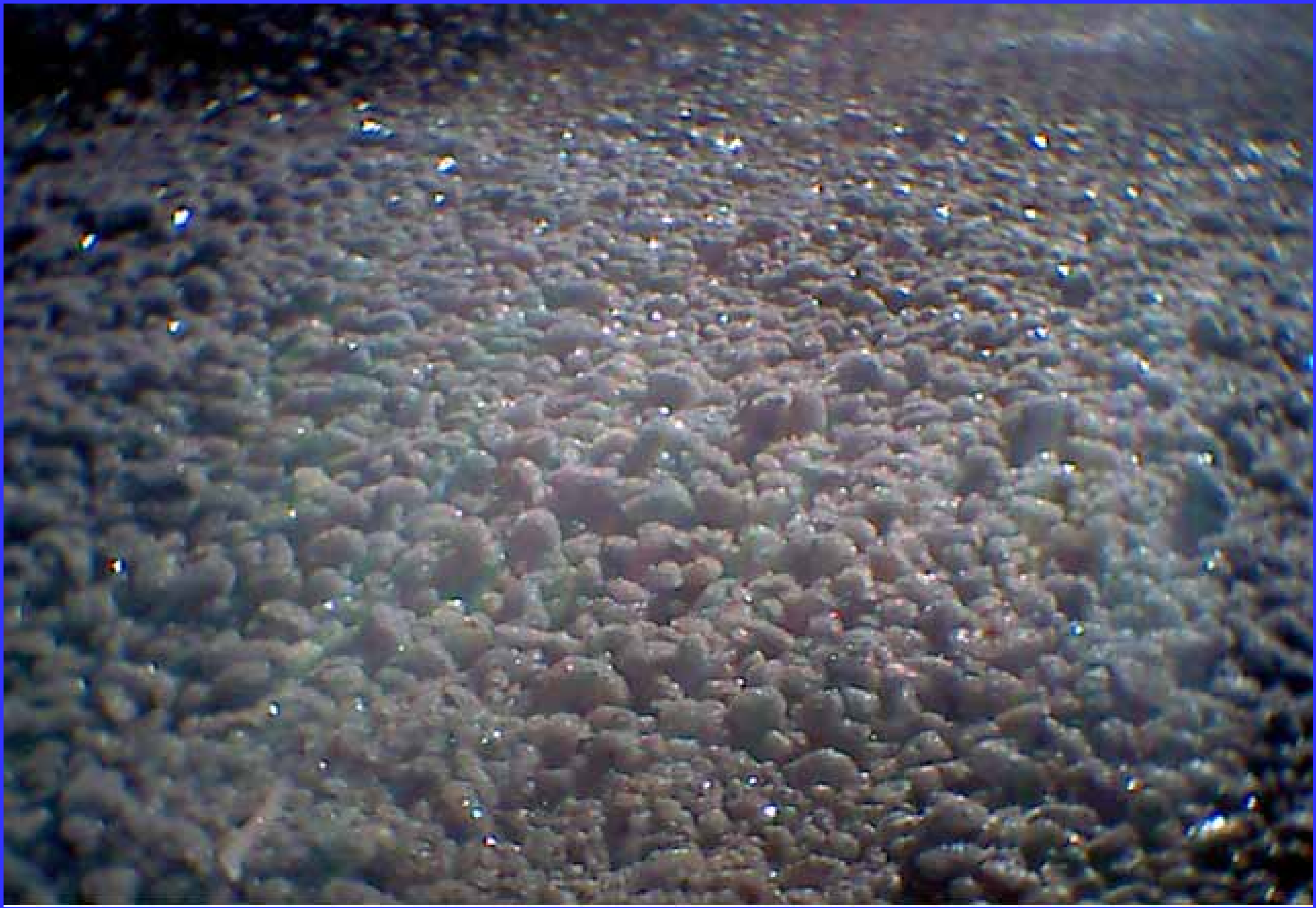
- DWR and CSUF evaluations agree on measured drifted rates for 1.5 nozzle height (0.5 vs 0.4 Kg/hr) but disagree on deposition distance 50 vs 200 meters.

- Approximate emission rates vary from 0.2 to 1.85 lb/hr depending on nozzle elevation (0.6% to 5.3% of total SE input)

- The 6 ft fence decreases the total emissions by interfering with the wind pattern at the nozzle level and by intercepting 99.4 to 94.7% of the total emissions before they leave the SE perimeter.

- A established salt tolerant tree barrier (30 ft or higher) placed within 100 yards of SE will contain nearly 99.9 % of salt that drifts outside the SE. It will allow placement of nozzles at a higher elevation, therefore increasing evaporation rates.

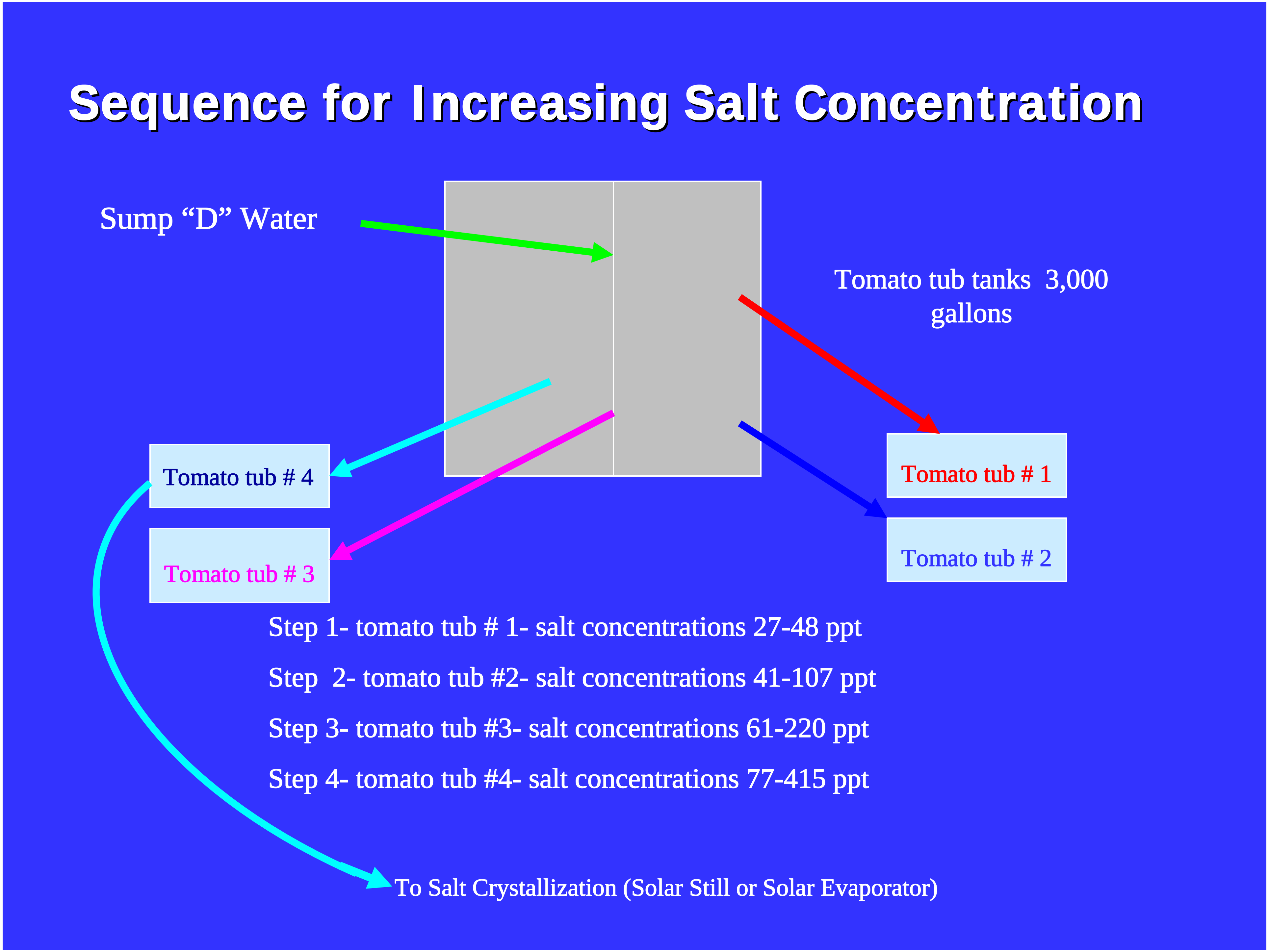
Salt Accumulation and Separation



Salt mixture on the solar evaporator surface

Extractable TDS Constituents Average % by Dry Weight:

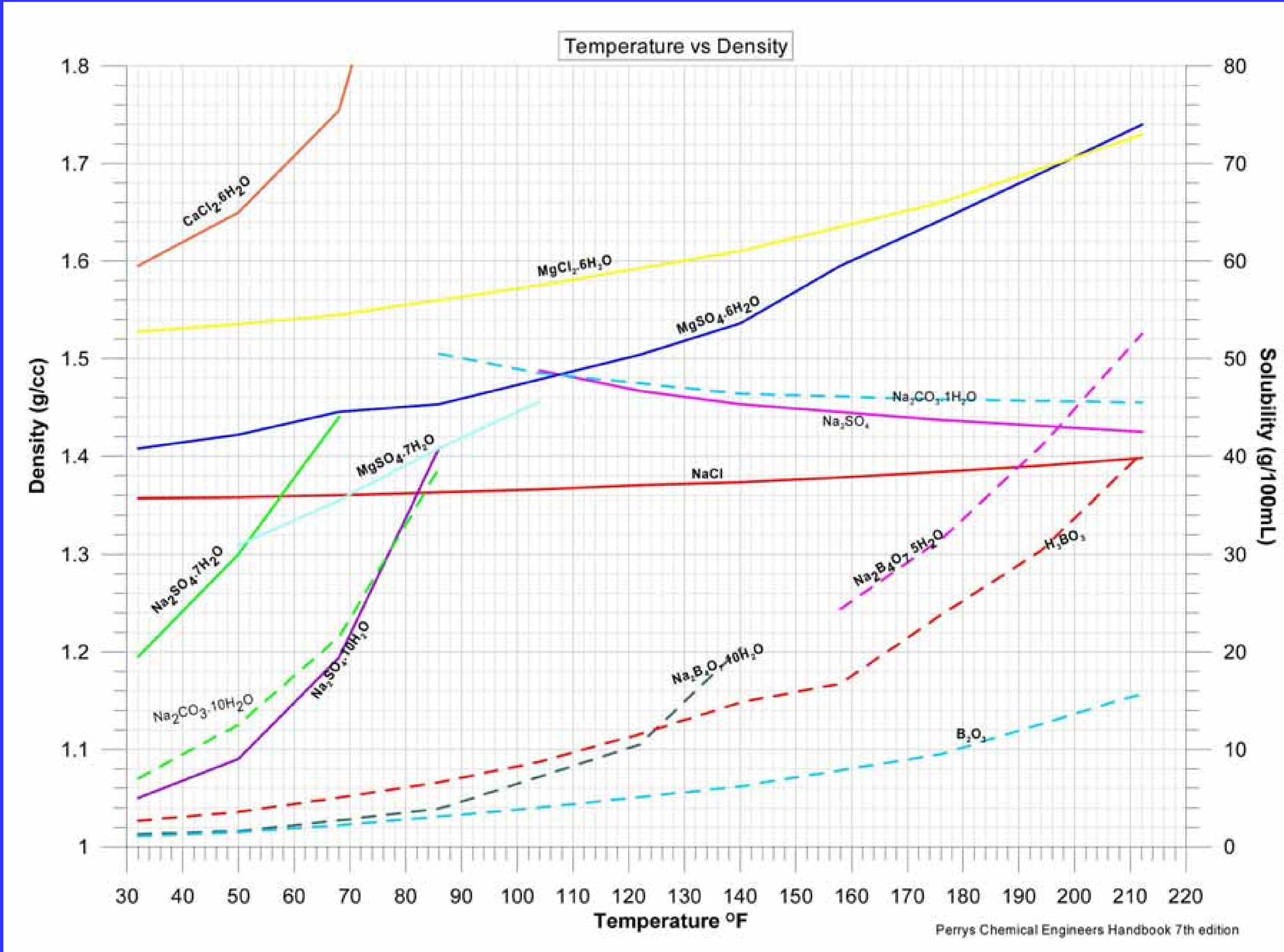
Sodium Sulfate	37%
Sodium Chloride	33%
Calcium Sulfate	16%
Magnesium Chloride	7%
Sodium Nitrate	3%
Calcium Carbonate	2%
Boron	1%
Potassium Chloride	0.8%
Selenium	0.01%
Other	0.19%



Sequence for Increasing Salt Concentration
Sump “D” Water
Tomato tub tanks 3,000 gallons
Tomato tub # 1
Tomato tub # 2
Tomato tub # 4
Tomato tub # 3
Step 1- tomato tub # 1- salt concentrations 27-48 ppt
Step 2- tomato tub #2- salt concentrations 41-107 ppt
Step 3- tomato tub #3- salt concentrations 61-220 ppt
Step 4- tomato tub #4- salt concentrations 77-415 ppt
To Salt Crystallization (Solar Still or Solar Evaporator)

Increasing Salt Concentration

Salt accumulated at a green house at RRR


Temperature vs Density
Density (g/cc)
Solubility (g/100mL)
Temperature °F
$CaCl_2.6H_2O$
$MgCl_2.6H_2O$
$MgSO_4.6H_2O$
$Na_2CO_3.1H_2O$
Na_2SO_4
$MgSO_4.7H_2O$
NaCl
$Na_2SO_4.7H_2O$
$Na_2B_4O_7.5H_2O$
H_3BO_3
$Na_2SO_4.10H_2O$
$Na_2B_4O_7.10H_2O$
$Na_2CO_3.10H_2O$
B_2O_3
Perrys Chemical Engineers Handbook 7th edition

Sodium sulfate is the dominating salt in the mixture

Approximate Value of Dissolved Salt Components
RRR Sump “D” Drainage Water (10 af)
TDS: 10,000 mg/L with 1 mg/L Se

	Quantity	Unit Value	Market Value	% Value
Sodium Chloride	46.1 tons/yr	$25/ton	$1,152	8%
Calcium Bicarbonate	2.8 tons/yr	$7.5/ton	$20	<1%
Sodium Nitrate	5.6 tons/yr	$300/ton	$1690	12%
Boron	1.4 tons/yr	$425/ton	$610	4%
Magnesium Chloride	9.2 tons/yr	$255/ton	$2,338	16%
Gypsum (calcinated)	19.3 tons/yr	$30/ton	$580	4%
Sodium Sulfate	51.5 tons/yr	$134/ton	$6,898	49%
Selenium	22 lbs/yr	$52/lb	$1,149	8%
Total			$14,438	100%

Source USGS Mineral Commodity Statistics (Prices are fob at mine 2006)

Solar Evaporator Estimated Costs

Pilot Solar Evaporator Estimated Costs (1 Acre)

Gravel delivered and placed		$7,500	
Tile Drain System and Sump		$5,000	
Grading and Excavation		$4,000	
Pumps		$5,000	
Spray System inc. tips		$2,000	
Corrugated Drain Pipes		$2,500	
Drift Fence		$6,250	
Land (SJV Westside)		$5,000	
Engineering fees and permits (20%)		$9,313	
Total Capital Costs		$46,563	
Capital Costs	20 yr at 7%	$4,395	year
Pumping Costs		$6,983	year
O&M		$5,400	year
Total Combined Costs		$16,778	year
Brine Water Evaporated		16.50	af per ac/yr
Total Unit Cost		$1,017	per af

Conclusions

With fan sprinklers at 1.5 ft, the SE achieved 3.3 times the rate of pan evaporation.

A minimum of 16.5 acre-feet per acre per year of subsurface drainage water can be evaporated at the pilot SE.

Salt drift can be minimized with a screened 6-ft fence resulting in drift rates up to 1lb per hour of operation. This represents about 1% of the total salt volume.

At higher sprinkler elevations the evaporation rates can be increased substantially, but a taller barrier will be needed to control salt drift.

Pilot demonstration project results indicate that is feasible to design, construct, and operate a solar evaporator for IFDM.

It could be used to manage concentrate from desalination processes and effluent from industrial processes

Salts can be stored and separated in different components (need large salt volume to attract commercial operations)